High Intensity Neutrino Source (HINS) Linac at Meson Detector Building Test Facility

Section IV - Chapter 2

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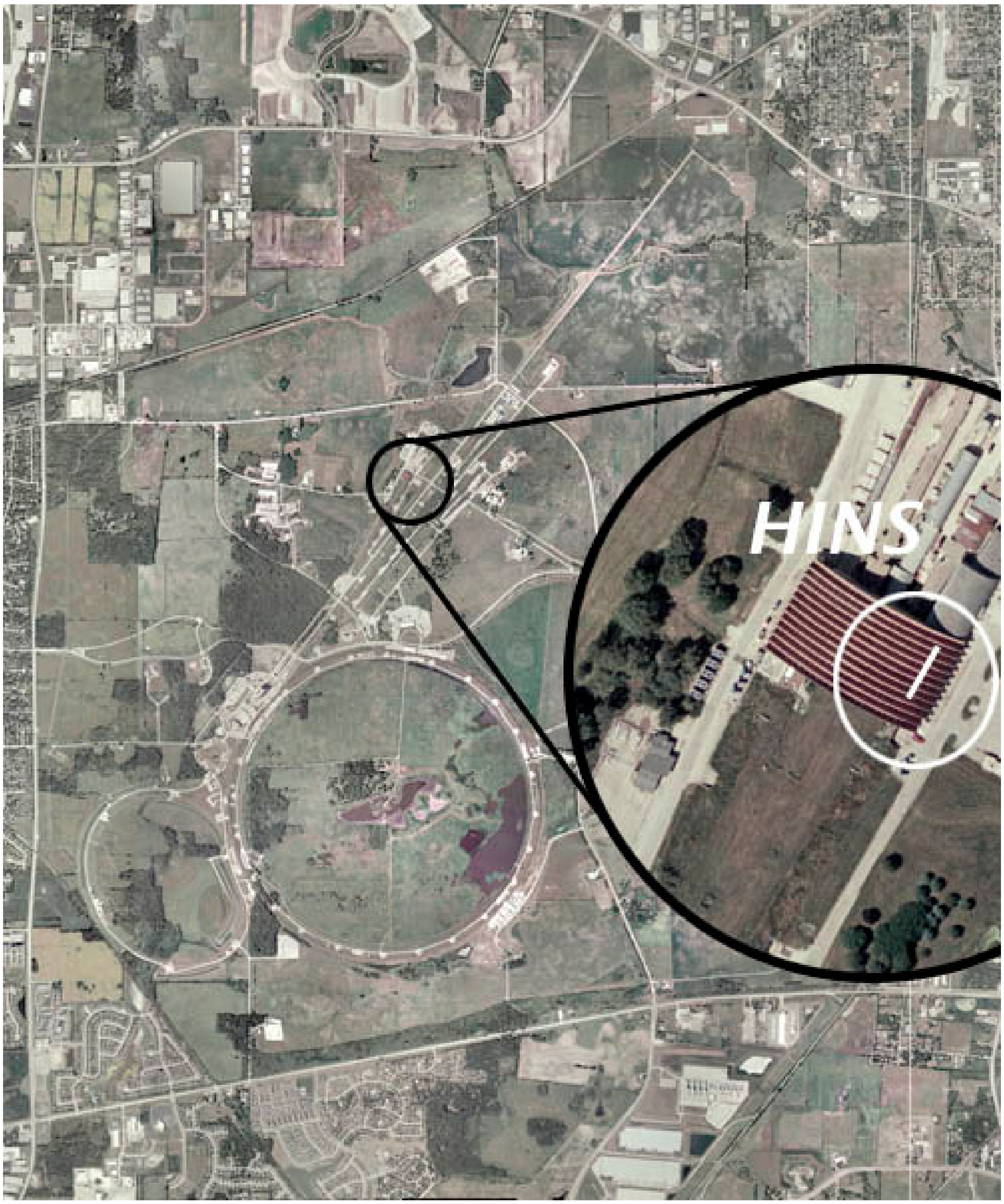
IV - 2.1 HINS Location on Fermilab Site

The HINS Linac occupies the east side of the Meson Detector Building.



IV - 2.2 Inventory of Hazards

The following table lists the identified hazards found in the High Intensity Neutrino Source Linac and its support equipment. All hazards with an * have been discussed in Chapters 1-10 of the Fermilab Safety Assessment Document and are covered no further in this section.

Radiation Particle beams and prompt radiation Residual component activation X-Ray producing devices Lasers High Power RF (non-ionizing)	**Kinetic Energy** Power tools* Pumps and motors*
Toxic Materials Lead shielding * Beryllium components *	**Potential Energy** Crane operations* Compressed gases* Vacuum / pressure vessels* Vacuum pumps*
Flammable & Combustible Materials Cables* Flammable Gases	**Magnetic Fields** Fringe fields*
Electrical Energy Stored energy exposure High voltage exposure	**Gaseous Hazards** Oxygen Deficiency Hazards (ODH) Sulfur Hexafluoride (SF_6)
Thermal Energy	**Access / Egress** Life Safety Egress

IV - 2.3 Introduction

This Section IV, Chapter 2 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the High Intensity Neutrino Source (HINS) Linac that occupies the east side of the Meson Detector Building.

IV - 2.3.1 Purpose of HINS Linac

The HINS Research and Development (R&D) program will investigate and demonstrate accelerator technology that might find application in a high energy, high intensity superconducting Linac to serve the next generation of neutrino physics experiments or muon storage ring/collider R&D activities. The HINS Linac is built to serve these objectives.

IV - 2.3.2 Description of HINS Linac

The scope of the HINS Linac is a linear proton/H^- ion accelerator with beam energies up to 10 MeV. It will operate to test and demonstrate accelerator components, technologies, and beam chopping methods and to facilitate the development and testing of beam instrumentation and diagnostic methods and devices.

The HINS Linac has a potential capability of 25mA beam current in a three-millisecond pulse at a 1% duty cycle for a maximum beam intensity of 6.1E18 protons or H^- ions per hour. Typical operation will be half that hourly rate or less. The HINS Linac is expected to operate less than 6 hrs/day, 4 days/week/, and 30 weeks per year[1]. Assuming these rates, the HINS Linac will produce no more than 2.0E21 protons at 10 MeV per year.

Facilities for the HINS Linac are installed and operated in the east side of the Meson Detector Building (MDB). The HINS Linac beam line is housed within the HINS Linac enclosure, a concrete structure built for radiation shielding, shown in Figure 1.

The HINS Linac comprises a 50 keV proton or H^- ion source, a Radio Frequency Quadrupole (RFQ), a 2.5 MeV Medium Energy Beam Transport (MEBT) line including beam choppers and absorbers, and ultimately an acceleration section to produce a final beam energy of up to 10 MeV. Beam diagnostics sections and suitable beam absorbers are located within the Linac enclosure downstream of the accelerating sections. No beam is transported outside the HINS Linac enclosure that is shown in Figure 1.

Ancillary power supplies, controls and diagnostics equipment, and other accelerator support equipment are located outside the Linac enclosure. A 325-MHz, pulsed radio frequency (RF) power source consisting of a 2.5 MW klystron and modulator occupies the Klystron and Modulator Area shown in Figure 1 and provides pulsed power for the RF cavities of the HINS Linac.

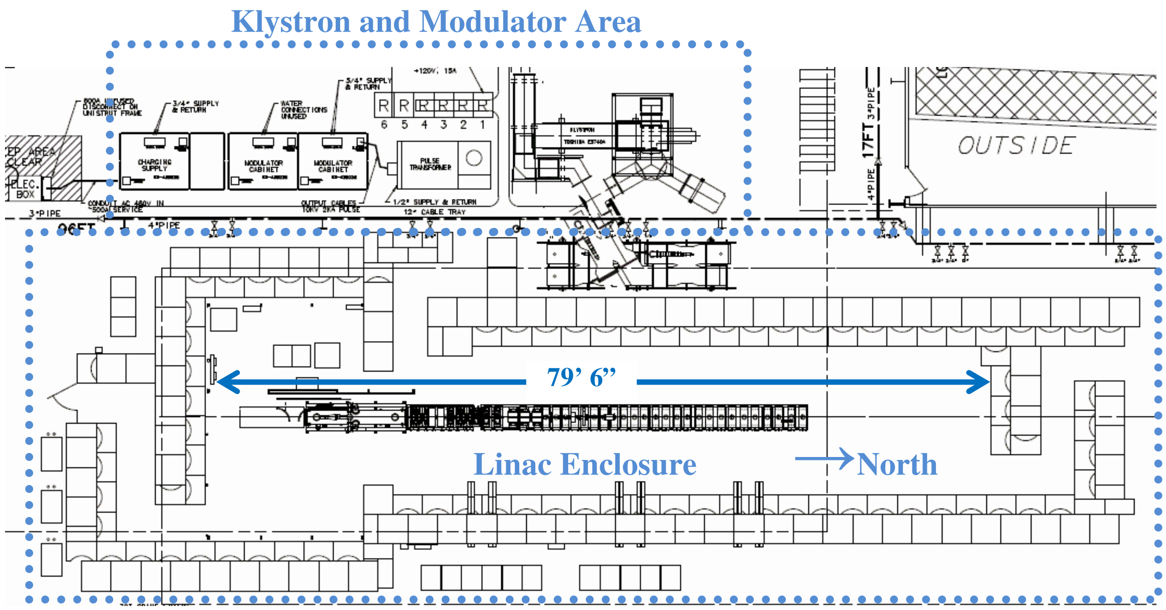


Figure 1: Layout of HINS Linac enclosure, beam line and support equipment in the east side of MDB.

IV - 2.3.3 Operating Modes

HINS Linac beam is accelerated from the ion source located at the south (left in Figure 1) end of the enclosure through the Linac toward the north (right) end of the enclosure where it is deposited in a suitably designed beam absorber. No beam is transported outside the HINS Linac enclosure that is shown in Figure 1.

Beam is accelerated in a pulsed mode with a pulsed beam current of 25 mA, a duty cycle not exceeding 1%, and a maximum pulse length of three milliseconds. The maximum beam intensity is 6.1E18 protons (or H^- ions) per hour. The maximum beam energy is 10 MeV. The HINS Linac will produce no more than 2.0E21 protons at 10 MeV per year.

The detailed configuration of the HINS Linac, beam line, and beam absorbers within the enclosure will change as the Linac is commissioned in phases and as R&D objectives are met and redefined. Specific Run Conditions are established for each configuration and the limiting scope of all such configurations is defined by the operating parameters described in the two paragraphs immediately above and by the scope of the HINS Linac Shielding Assessment[1].

IV - 2.4 Safety Assessment

The unique accelerator-specific hazards of the HINS Linac are analyzed in this section.

IV - 2.4.1 Radiological Hazards

The HINS Linac presents radiological hazards in the form of prompt and residual ionizing radiation from particle beams, x-rays from high gradient accelerating cavities, and non-ionizing radiation from lasers and high-power RF systems.

IV - 2.4.1.1 Ionizing Radiation

Prompt ionizing radiation is generated while the HINS Linac is accelerating a proton or H^- ion beam. The interlocked HINS Linac enclosure is designed and constructed to limit exposure to personnel outside the enclosure to prompt ionizing radiation according to the standards set in the Fermilab Radiological Control Manual (FRCM)[2].

The efficacy of the shielding provided by the enclosure as constructed is specifically and quantitatively evaluated and documented in the HINS Linac Shielding Assessment. Section 8 of that assessment stipulates the key assumptions in order for the conclusions of the assessment to be valid at the stated maximum beam intensity and energy:

- *The beam energy shall not exceed 10 MeV.*
- *The instantaneous beam intensity shall not exceed 3.3E16 protons or H- ions per second.*
- *The average beam intensity shall not exceed 6.1E18 protons or H- ions per hour.*
- *The beam line and in particular the absorber location must correspond to one of the four configurations considered in the shielding assessment.*
- *The three labyrinths must be equipped with gates to create an exclusion area for beam operations.*
- *The straight water penetration in the west wall of the linac area has to be filled with sandbags.*
- *Radiation detectors are installed and interlocked to the beam in order to detect any accident conditions and disable the beam within 1 sec.*

The HINS Linac Shielding Assessment concludes:

- *We have analyzed the HINS linac shielding under normal and accident conditions.*

- *We have determined that based on the key assumptions listed, the facility is in conformance with all FRCM requirements and can be operated safely with the following beam parameters:*
  - *Maximum intensity is 6.1E18 protons or H- ions per hour;*
  - *Maximum energy is 10 MeV;*
  - *Maximum intensity per second is 3.3E16 protons or H- ions.*
- *The activation of the air, groundwater, and beam elements is expected to be minimal and imposes no constraints on the amount of beam that can be delivered in a year.*

IV - 2.4.1.2 Residual Activation

Loss and absorption of the HINS Linac beam will result in activation of beam absorbers, intercepting beam instrumentation devices, and other beam line components. The activation level and quantity of activated material will not be unique relative to other accelerators at Fermilab. The residual activation potentiality is strongly energy-dependent through the 10-MeV energy range of the HINS Linac beam. No activation results from protons at energies below ~3 MeV.

Results of a MARS[3] simulation of the 10-MeV absorber, including residual activation, are reported in the "HINS Beam Absorber MARS15 Simulations (extended)" [4]. Slide 15 of that report shows that the predicted residual activation at the outer surface of the absorber shielding is 0.2 mrem/hr on contact after 30 days of maximum intensity operation followed by one day of cool down.

The same reference shows 10 mSv/hr (1 R/hr) residual activation on the absorber's internal surface. This is taken as an upper limit for residual activation anywhere in the system, including that resulting from an extended accidental 100% beam loss condition. As required by the HINS Linac Shielding Assessment, interlocked radiation detectors with a one-second response time are installed to limit accidental doses due to prompt radiation. These detectors will likewise serve to limit accidental residual activation by preventing continuous operation with high losses. Operation under conditions of detector trips will necessarily be infrequent and of limited duration. Assuming an unlikely long-term 5% average duty factor with these conditions, the worst case residual activation would be 50 mrem/hr. At locations where the beam energy is below 10 MeV, the situation only improves.

Residual activation hazards will be managed within the As Low As Reasonably Achievable (ALARA) program established throughout the Fermilab accelerator complex and as prescribed in the Fermilab Radiological Control Manual.

IV - 2.4.1.3 X-Ray Producing Devices

The radio-frequency accelerating cavities in the HINS Linac beam line contain electromagnetic fields of sufficient magnitude to accelerate 'dark-current' electrons to energies capable of producing x-rays. "Estimate of RF Cavity X-rays in the HINS Linac Enclosure and Shielding Required"[5] documents the analysis of this hazard. For superconducting RF cavities, excluded from the HINS Linac by this SAD, that analysis concludes that "the worst case dose outside the enclosure [on the enclosure roof] due to RF cavity-produced x-rays is calculated to be of order 0.05 mrem/hr." For the normal copper cavities allowed within this SAD, the x-ray source term documented in that analysis is a factor of three lower still. This is well within the FRCM parameters for a Minimal Occupancy Controlled Area which is the enclosure roof designation per the HINS Linac Shielding Assessment.

The safety interlock system for the HINS Linac shielding enclosure shall disable RF power to the cavities thereby eliminating the x-ray hazard whenever personnel access the enclosure.

The 325-MHz klystron RF power source for the accelerating cavities is also an x-ray producing source. X-ray shielding for the klystron is provided by the klystron manufacturer, Toshiba, and installed per manufacturer's specifications. Fermilab Radiological Control Technicians (RCTs), under the direction of the Accelerator Division (AD) Radiation Safety Officer (RSO), have verified that the x-ray level outside the shielding is well below the 0.25 mrem/hour threshold specified in the FRCM for an unlimited occupancy controlled area in which the klystron operates.

IV - 2.4.1.4 Radioactive Waste

Production of radioactive material is not an operational function of the HINS Linac. Waste minimization is an objective of both the HINS Linac design and its operational procedures. Nevertheless, accidental beam loss and, in the case of the beam absorbers and some beam diagnostics devices, intentional interception of the accelerated beam will result in activation of beam line elements. Maintenance and eventual disposal of these items implies radioactive waste. The relatively small scale and low beam energy of the HINS Linac indicate that the activation level and quantity of radioactive waste material produced will not be large.

Beam absorbers and small intercepting beam diagnostic components represent the items of highest activation, with surface exposure rates approaching 1 R/hr at contact with one-day cool down. The volume of material, all metals, at this activation level will be less than two cubic feet. Beam tubes, flanges, and other miscellaneous items are expected to be activated to levels of ≤50 mrem/hr on contact. These will total an approximate program life-time weight of two hundred pounds.

Radioactive waste hazards and disposal will be managed within the program established throughout the Fermilab accelerator complex and as prescribed in the FRCM.

IV - 2.4.1.5 Lasers

Class III and Class IV, near-infrared and visible lasers will be used in the HINS Linac enclosure for the purpose of beam diagnostics based on the principle of photo-detachment of electrons from H- ions.

The functional implementation of these systems will deliver light from a laser source via an enclosed, light-tight lumped optics channel or optical fibers to the particle beam within the beam vacuum chamber. The systems are designed with appropriate waste light absorbers to prevent large amplitude reflections once the light has interacted with the ion beam. The laser heads might be located either inside or outside the interlocked beam enclosure. Any location in the Linac beam line between RFQ and beam absorber is a candidate interaction point for ion beam and laser light. Not more than two operational laser installations are anticipated at any one time.

These lasers and the operation thereof are subject to the stipulations of the laser chapter of the Fermilab Environment, Safety, and Health Manual (FESHM)[6]. The Laser Safety Officer (LSO), is responsible for assuring all laser safety precautions are implemented and followed.

IV - 2.4.1.6 Non-Ionizing Radiation

Hazardous levels of radio frequency electromagnetic energy are generated by the RF power sources for the HINS Linac; however, this energy is not radiated. The RF energy is contained within waveguide, coaxial transmission lines, or accelerating cavities. Specific “Lock-out/Tag-out” procedures are in place to establish safe conditions for personnel working on these systems. Periodic surveys for stray RF fields are performed by the AD Environment, Safety and Health (ES&H) Department.

IV - 2.4.2 Toxic Materials

As supplied by the manufacturer, the 325-MHz, 2.5-MW RF klystron is outfitted with lead shielding to attenuate x-rays produced by the electron beam within the klystron. The lead is in three forms: 1) some amount integral to the klystron assembly itself; 2) a painted lead-lined housing approximately 3' long by 3' wide by 6' high enclosing the RF power output window section of the klystron; and 3) two soft lead sheets, labeled and protected, wrapping the water cooling connections at the collector end of the klystron.

The lead is enclosed or painted to minimize the potential for personnel exposure.

IV - 2.4.3 Gaseous Hazards

A section of the RF power distribution system serving the HINS RFQ requires sulfur hexafluoride (SF_6) to prevent electrical breakdown. Use of this gas offers the possibility of creating an oxygen deficiency hazard (ODH).

IV - 2.4.3.1 Oxygen Deficiency Hazards

IV - 2.4.3.1.1 Sulfur Hexafluoride

Sulfur Hexafluoride is an inert, non-toxic gas used to increase the dielectric capacity of high power RF distribution components. Electrical breakdown in a SF_6 atmosphere can produce toxic substances. The coaxial RF power splitter serving the HINS RFQ requires a static fill of SF_6 for reliable operation at the nominal RF power level.

SF_6 usage and procedures for the HINS Linac are described in "HINS Sulfur Hexafluoride System Policies and Procedures"[7]. Per that document, the maximum quantity of SF_6 is four cubic feet confined to a short section of the RF power distribution line to the RFQ in the Ion Source/RFQ end of the enclosure. The procedure requires leak-checking the RF transmission line before filling with SF_6 to prevent accidental release of an unexpected volume of the gas that might cause an ODH hazard. This section of RF line is filled with SF_6 from a compressed gas cylinder located outside the enclosure and is physically disconnected from the gas cylinder when filled. The procedure also specifies ventilation required when SF_6 is released from the transmission line. SF_6 is a potent greenhouse gas, amounts released will be minimized, documented, and included in the annual reporting of this gas to DOE.The Ion Source/RFQ end of the enclosure comprises a floor area of about 384 sq. ft. and a ceiling height of 13.5 ft, for a volume of 5184 cubic feet. Four cubic feet of SF_6 represents only 0.08% of that volume and thus does not present an ODH hazard.

IV - 2.4.4 Flammable Gases

IV - 2.4.4.1 Hydrogen

Hydrogen gas is required by the ion source for the HINS Linac, whether for protons or H^- ions.

The hydrogen is provided by a single, manufacturer-supplied cylinder containing 35 CF of 6-grade H_2 under a maximum pressure of 1800 psig. The cylinder is located in the HINS Linac enclosure beneath the ion source. It connects to the ion source via a low conductance gas regulation system. Vacuum pumps that remove waste gas from the ion source are vented to the outside of the HINS Linac enclosure. Spare cylinders are not stored in the HINS Linac enclosure. This quantity of hydrogen qualifies the installation as a Flammable Gas Risk Class 0 area per FESHM guidelines. The area is ventilated and a hydrogen monitoring detector is installed as part of the facility's VESDA fire protection network, which is actively monitored by the Fermilab FIRUS system.

Detailed analysis of the hydrogen safety issues and identification of the hazard mitigations are found in "Hydrogen Safety Considerations for HINS Proton Source in Meson Building"[8].

IV - 2.4.5 Access/Egress

IV - 2.4.5.1 HINS Linac Shielding Enclosure Access/Egress

As shown in Figure 1, the HINS Linac enclosure has three short labyrinths for personnel access and egress located on the north, south, and west sides of the enclosure. Every point in the enclosure has two egress points within a distance of forty feet. A screened gate at the exterior end of each labyrinth is lockable to prevent access from the outside, but freely opened from the inside.

IV - 2.4.6 Unique Electrical or Magnetic Field Hazards

The HINS Linac electrical hazards fall within the scope described in the "Electrical Hazards" paragraph of Section 1 of the Fermilab SAD. The notable HINS accelerator-specific electrical hazards are described here.

The power supplies and modulators for the RF power sources, e.g. the 2.5 MW klystron, represent sources of high voltage and high stored electrical energy. These hazards are mitigated by containing this equipment in interlocked cabinets and by following written LockOut/TagOut procedures that conform to FESHM requirements for access to the cabinets and maintenance of the equipment.

The ion source and its power supplies present high voltage and high stored electrical energy hazards. These hazards are mitigated by electrically shielding and enclosing the high voltage elements and energy storage components and by following a specific LockOut/TagOut procedure that conforms to the FESHM requirements for accessing the components and maintaining the systems.

There are no unique magnetic field hazards in the HINS Linac.

IV - 2.5 Credited Controls

IV - 2.5.1 Passive Controls

Passive controls are employed to the fullest extent possible wherever safety controls are required in the HINS Linac.

IV - 2.5.1.1 Permanent Shielding Including Labyrinths

The HINS Linac enclosure is designed and constructed as a permanent concrete radiation shield. The enclosure with its access/egress labyrinths and utilities penetrations is fully described and the shielding efficacy quantitatively analyzed in the HINS Linac Radiation Shielding Assessment.

For normal operating conditions, the assessment finds that the permanent shielding as designed is adequate to limit maximum dose rates to:

- less than 0.25 mrem/hr at floor level outside the enclosure;
- less than 5 mrem/hr at the labyrinths entrances and at all heights 10.5 feet above floor level including the enclosure roof.

For accident conditions, the assessment finds that the permanent shielding, supplemented with interlocked radiation detectors, will limit the maximum accidental dose to:

- less than 5 mrem at floor level outside the enclosure;
- less than 100 mrem at heights 10.5 feet above floor level including the enclosure roof.

IV - 2.5.1.2 Moveable Shielding

Moveable shielding is not integral to the radiation shielding design of the HINS Linac. Moveable shielding will be employed as necessary to achieve ALARA objectives for any relevant maintenance tasks. Due to the relatively low beam energy of the HINS Linac, worst case unshielded residual radiation levels are expected to be no more than 50 mrem/hr (see Residual Activation section above).

IV - 2.5.1.3 Penetration Shielding

The HINS Linac enclosure has four straight-through utility penetrations and three sections with three-legged cable conduit penetrations. The HINS Linac Radiation Shielding Assessment fully describes the shielding associated with each penetration and assesses the maximum corresponding radiation dose. The assessment finds that doses outside any penetration are limited to less than 0.25 mrem/hr under normal operating conditions and to substantially less than 5 mrem for the worst case accident.

IV - 2.5.2 Active Controls

As described in Chapters 1-10 of the Fermilab SAD, active systems are designed to reduce the risk of accelerator operations hazards to an acceptable level.

IV - 2.5.2.1 Radiation Safety Interlock System

The HINS Linac enclosure employs a Radiation Safety Interlock System with the characteristics described in Section I of the Fermilab SAD. This system conforms to requirements of the FRCM.

There are interlocked gates at each of the three entrance labyrinths into the HINS Linac enclosure. The interlock system inhibits acceleration of beam beyond 50 keV and inhibits application of x-ray producing RF power to accelerating cavities except when the Linac enclosure is properly secured and locked.

The safety interlock system inhibits beam by controlling redundant critical devices; in this case, two physical beam stops in the Low Energy Beam Transport line immediately downstream of the ion source. Status of the beam stops is actively monitored, and if a failure is sensed, the interlock system shuts off the 50 kV ion source high voltage power supply.

The safety interlock system inhibits x-ray producing RF power to the accelerating cavities via control of an electronic permit to the RF power system.

Trained and qualified personnel are required to search and secure the enclosure before permits from the safety interlock system may be reestablished following any personnel access to the enclosure, except under strictly specified controlled access conditions.

IV - 2.5.2.2 Flammable Gas Detection Systems

In accordance with FESHM, a Flammable Gas Detection System is installed in conjunction with the HINS ion source hydrogen supply to warn and protect personnel and property from a potentially explosive atmosphere in the HINS Linac enclosure.

Specifically, a hydrogen sensor is installed above the HINS ion source hydrogen cylinder near the ceiling of the enclosure. This hydrogen sensor is integrated into the VESDA system serving the HINS area of the Meson Detector Building to provide both a local alarm and, via the Fermilab FIRUS system, a remote alarm. The use of hydrogen including the hydrogen detection system is included among the HINS Linac systems reviewed by the Fermilab Hydrogen Target Safety Subcommittee and approved by the AD Head before flammable gases or liquids may be introduced into the enclosure.

IV - 2.5.3 Administrative Controls

All Fermilab HINS Linac accelerator operations with the potential to affect the safety of employees, researchers, or the public, or to adversely affect the environment, are performed using approved laboratory, division, or department procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed below.

IV - 2.5.3.1 Summary of beam operating and safety envelope parameters

The HINS Linac is assessed for a pulsed proton or H^- beam with maximum ion energy of 10 MeV and maximum accelerated beam intensity of 3.3E16 ions per second (6.1E18 per hour). The maximum integrated beam intensity shall be no more than 2.0E21 protons at 10 MeV per year. No beam is transported outside the HINS Linac enclosure.

Accelerator operational approvals shall be obtained through the standard channels and procedures administered by the AD ES&H Department, the AD Head, and the ES&H Section.

Beam Permit and Run Condition documents shall identify the beam power and operating parameters allowed for the HINS Linac accelerator within the current Accelerator Safety Envelope. The Beam Permit specifies beam power limits as determined and approved by the AD Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and HINS Linac program manager. The Run Condition for the HINS Linac describes the operating configuration as reviewed by the AD RSO, AD Operations Head, and HINS Linac Program Manager and as approved by the AD Head.

IV - 2.5.3.2 Description of machine operations

Commissioning, normal operations, and emergency management of the HINS Linac are all conducted under the auspices of the AD Headquarters, the AD ES&H Department, and the AD Operations Department.

The HINS Program Manager and the HINS Run Coordinator are specifically responsible for HINS operations and are the points of contact for the organizations within the AD. The HINS Program Manager reports to the Fermilab Associate Director for Accelerators on strategic and program management matters. The HINS Run Coordinator, assigned by and reporting to the HINS Program Manager, is responsible for the planning and coordination of daily HINS operations.

The HINS Linac is operated by a minimum of two persons, at least one of whom is a trained and qualified HINS operator, physically present in the Meson Detector Building with explicit purpose of operating the Linac. The AD Operations Department controls a system of keys that are required to operate major subsystems of the HINS Linac. The AD Operations Department maintains a list of individuals trained to conduct HINS operations and signs out HINS keys accordingly to only qualified persons. The HINS Program Manager and HINS Run Coordinator, under the guidance of the AD ES&H Department and in conjunction with the AD Operations Department, are responsible for defining, developing, maintaining, and administering the HINS training programs. In particular, HINS operator training is performed and documented under the auspices of the appointed HINS Linac Specialist from the AD Operations Department and according to that Department's standard practices that apply for Main Control Room operators.

All emergency situations and off-normal HINS operational incidents are reported to the on-duty AD Operations Department Crew Chief and handled per AD Operations Department protocols.

IV - 2.6 Summary & Conclusion

Specific hazards associated with commissioning and operation of the HINS Linac are identified and assessed in this chapter of the Fermilab Safety Assessment. The designs, controls, and procedures to mitigate HINS Linac specific hazards are identified and described. In addition to these specific safety considerations, the HINS Linac is subject to the global and more generic safety requirements, controls and procedures outlined in Section 1 of this Fermilab Safety Assessment Document.

Within the specific and generic considerations of this assessment, within the scope of the HINS Linac Radiation Shielding Assessment, and within the specified maximum beam operating parameters, the HINS Linac can be constructed, commissioned, and operated with a level of safety that will protect people and property and is equal to or exceeding that currently prescribed by DOE orders and Fermilab regulations as put forth in the FESHM and the FRCM.

IV - 2.7 Glossary, Acronyms

AD	Fermilab Accelerator Division
ALARA	As Low As Reasonably Achievable
D&D	Decontamination and Decommissioning
DOE	United States Department of Energy
ES&H	Environment, Safety and Health
EA	Environmental Assessment
FESHM	Fermilab Environment, Safety, and Health Manual
FRCM	Fermilab Radiological Control Manual
HINS	High Intensity Neutrino Source
LSO	Laser Safety Officer
MDB	Meson Detector Building
MEBT	Medium Energy Beam Transport
ODH	Oxygen Deficiency Hazard
R&D	Research and Development
RF	Radio Frequency
RFQ	Radio Frequency Quadrupole
RSO	Radiation Safety Officer
SAD	Safety Assessment Document
SF_6	Sulfur Hexafluoride
VESDA	Very Early Smoke Detection and Alarm

IV - 2.8 References

[1] P. Kasper, HINS Linac Shielding Assessment, January 26, 2011. ESH Section Document Database, ESH-doc-1480.

[2] Fermilab Radiological Control Manual. - The current web link is: http://esh.fnal.gov/xms/FRCM

[3] N.V. Mokhov, "The MARS Code System User's Guide", Fermilab-FN-628 (1995);N.V. Mokhov, O.E. Krivosheev, "MARS Code Status", Proc. Monte Carlo 2000 Conf., p. 943, Lisbon, October 23-26, 2000; Fermilab-Conf-00/181 (2000)

[4] N. Mokhov, "HINS Beam Absorber MARS15 Simulations (extended)", Fermilab Project X Document Database, Project X-doc-598

[5] R. Webber, "Estimate of RF Cavity X-rays in the HINS Linac Enclosure and Shielding Required", Fermilab Project X Document Database, Project X-doc-583

[6] Fermilab Environment, Safety, and Health Manual. – The current web link is: http://esh.fnal.gov/xms/FESHM

[7] R. Madrak, "HINS Sulfur Hexafluoride System Policies and Procedures", Fermilab Project X Document Database, Project X-doc-477

[8] H. Piekarz, "Hydrogen Safety Considerations for HINS Proton Source in Meson Building", Fermilab Project X Document Database, Project X-doc-591